A DAY AT THE FITZALAN STEEL AND FILE-WORKS, SHEFFIELD.

[Steel-Casting.—Furnaces, Crucibles, Mould, Ingots, &c.]

"FROM what country and in what form is *steel* procured?" We should probably be correct in surmising that this question has occurred to many who are familiar enough with the appearance and the use of steel. Whether this valuable metal is a simple substance, forming narrow veins in hard rock; whether it occupies thick layers or beds beneath the earth's surface, like coal and rock-salt; whether it is found in rounded lumps or crude masses, scattered irregularly in mining districts; whether it is formed chemically from a mixture of several different substances, by the aid of heat and liquefaction, and with all the appliances of retorts, crucibles, and furnaces; whether it contains iron, or *is* iron, and how (if it be iron) the change from one form to the other is brought about; whether there are any steel-mines, and, if so, where they are situated—all these are points which are by no means so generally understood as they deserve to be; and it will not be a misappropriation of time if we devote a "Day" to the subject.

Steel is a combination of iron and carbon. Black-lead, of which drawing-pencils are made, is also composed principally of iron and carbon. Cast-iron, too, is a compound containing pure iron and carbon. The striking differences between these three substances arise in a twofold manner:—from the relative proportion between the two ingredients, and from the manner in which the union is brought about. Thus, malleable iron, such as is formed into bars and wire, contains a very little carbon; steel contains rather more; cast-iron contains a variable quantity according to the purposes to which it is to be applied, but always a greater proportion than steel and a less proportion than plumbago (or, as it is misnamed, "black-lead"). A mere difference in the relative proportion of the two ingredients, therefore, will not suffice to explain the difference between iron and steel. Steel, in its composition, occupies a middle place between malleable iron and cast-iron; but its qualities are very different from either, and these qualities appear to be due to the manner in which the two ingredients combine. Sometimes the combination presents a granulated texture, sometimes fibrous, sometimes crystalline, sometimes smooth and glittering, at other times rough and dull. Even scientific and practical men best qualified to master the subject have not yet shown why and how these changes take place; and it will therefore be out of place for us here to attempt any minute explanation. It will suffice for the present object to state the matter thus—that all our steel is made from bar-iron, which iron had been previously made from the ore by the processes of smelting, forging, &c., as described in our last Supplement; that the change from iron to steel is brought about by a long and careful series of processes, in the course of which carbon is absorbed by the iron; and that the steel so produced derives different qualities according to the subsequent processes which it undergoes.

It may appear strange, and indeed has about it something very remarkable, that notwithstanding the immensity of our iron manufacture, all our finest steel is made from iron brought from abroad; that this iron is procured from one single district, brought to one single English port, and consigned to the hands of one single firm. There appears reason to believe that this will not continue to be the case to so great an extent as it has been; but it is at present sufficiently near the truth to require at the outset a little explanation.

There is among the iron-mines of Sweden one which yields iron better fitted for making steel than any other yet discovered, at least in an available form; and English steel-makers have found this iron so valuable for their purpose, that they have been content to give a very high price for it, rather than employ English iron. The iron-mines of Sweden, taken collectively, are governed in a peculiar manner, which imparts the character of a very strict monopoly to the sale of Swedish iron in England. Each forge has its particular mark stamped on the bars of iron it produces, which is correctly copied into a register, with the name of the place where the establishment is situated—the names of the proprietors of the work—the commissioner or agent for the sale of iron—the assortment each makes, and to what country it is generally shipped—the quantity annually made by each work—the quantity which each work delivers to the government (which is about one per cent. on the quantity of the iron produced)—the determination of the quality of the iron of each work—the place and province in which the works are situated—the place from whence the iron is generally shipped—and how many forge-hammers there are at each work.

Among the mines thus regulated is that of Dannemora, which supplies England with iron for making steel. It is situated about thirty miles from Upsala, and has now been worked for nearly four centuries without failing in the abundance of its rich supply. The mine first belonged to the King of Sweden, then to the Archbishop of Upsala; but now it belongs to several private individuals, who work it separately on their own account. The ore differs in quality in different parts of the mine; some yielding 25 per cent. of cast-iron, and some as much as 75 per cent. The ore is blasted with gunpowder, and, after being broken in small pieces, is roasted. The smelting is effected in conical-shaped furnaces; the fuel employed being charcoal. The cast or 'pig' iron obtained is as white as silver, completely crystallized, and very brittle; and to convert this into malleable iron, it is heated in a bed of charcoal, and hammered out into bars, which are found to have a fibrous texture and a very tough quality. "The quantity of iron which this mine yields every year," says Mr. Scrivenor, from whose interesting 'History of the Iron Trade' these details are chiefly taken, "amounts to about four thousand tons; the whole of it is sent to England, to the house of Messrs. Sykes of Hull, where it is known by the name of Oregrund iron, taking its name from the port at which it is shipped. The first or best marks are 'hoop-L,' which sells at 40*l.* a ton, and OOCL, which sells at 39*l.* a ton; while the best Russian mark, the CCND, seldom fetches a higher price than 20*l.* a ton. The cause of the superiority of the Dannemora iron has never been explained. Some chemists ascribe it to the presence of manganese: Berzelius attributed it to the presence of the metal of silica; while others suppose it to arise from the nature of the process employed."

There is allusion above to 'marks,' which may need a little explanation. Each kind of iron has a reputation of its own, great or small, as the case may be; and the more highly it is esteemed, the more earnest are the makers in wishing that no other should be mistaken for it. Hence has arisen the custom of stamping some symbol on the end of each bar, by which the quality of the metal shall be known. Thus, C C N D is the symbol of the Russian iron brought from the mines of Prince Demidoff, a quality highly valued for many purposes; 'hoop-L' (that is, a letter L encompassed by a hoop) is the still more celebrated and valued Swedish Oregrund iron: while others are designated the 'double bullet,' the 'gridiron,' the 'steinbuck,' the 'C and Crown,' &c., according to the symbol stamped upon the bars.

We have found, then, that English steel is to a great degree made from foreign iron, brought to the port of Hull; and we have to trace it from thence. Some small portion goes to London, some to Newcastle, some to Birmingham; but all these are fragmentary and trifling compared with what goes to Sheffield. Here we find the centre of the steel trade, ramifying into a multiplicity of branches almost endless. Sheffield is as completely the metropolis of steel as Manchester is of cotton or Leeds of woollens. There is not a corner of the world where a British ship is allowed to enter but could exhibit some specimens or other of Sheffield steel goods. The rivers of Sheffield, if they could speak, would tell how busily they are employed in setting in motion the machinery for bringing steel to some one or other of its numerous forms; while the thoughts of the inhabitants, the names of many of the streets, the arrangement of the buildings, and the corporate usages of the town—all point to steel as being indeed a precious metal to Sheffield.

There are in this busy town several large establishments called Steel-Works, where the bar-iron is converted into steel and brought to a form fitted for the numerous workers in that metal. Some of these, according to the technical phraseology of the town, are 'tilts,' some are 'mills,' some are 'converting-works,' while a few comprise all the varieties within themselves. To understand this, it will be necessary to remark that manufactures are extremely subdivided at Sheffield, as at Birmingham; skill in one branch or sub-branch of manufacture having been deemed a sufficient reason for confining attention thereto, to the exclusion of others.

The cutlery trade generally of Sheffield will not come under our notice in the present article, else we should have to speak of this subdivision more fully; but it will be sufficient, in reference to steel, to state that some works or manufacturers are wholly occupied in *converting*, or making the crudest form of steel; others in *tilting*, or giving a further development to the steel; others in *casting*, or giving to steel a still higher quality by pouring it into ingots or moulds in a liquid state; and others in *milling* or *rolling*, whereby the steel is brought into the form either of bars or of sheets; while in some few cases the converting, the tilting, the casting, and the rolling are all carried on in one establishment.

Among the Works last alluded to, we have been favoured with access to the *Fitzalan Steel-Works* of Messrs. Marriott and Atkinson, which, besides exhibiting the various processes of steel-making, are well fitted to illustrate our subject, inasmuch as the *file manufacture* (one of the most important in which steel is employed) is there conducted on a large scale.

These Works are situated at Attercliffe, an eastern suburb of Sheffield. The whole neighbourhood is singularly favoured as to facilities for manufactures. Sheffield is in a hollow, nearly surrounded by hills; and several small rivers flow between these hills into the hollow, thus affording moving-power for a large number of water-wheels. Attercliffe is situated at a part of the district where all these streams have become one, and where also a canal opens a communica-

tion between Sheffield and the port of Hull, so that there is both motive-power and transit-power at command.

The Fitzalan Works occupy a quadrangular space surrounded by buildings, on the north bank of the Sheffield Canal. When within the entrance-gates we find a quadrangle having a large tank or reservoir near the centre, and around it are the various workshops for conducting the manufacturing processes. On the right hand are the 'converting' furnaces, where the iron is first made to assume the form of steel; opposite are the 'tilting' and 'shearing' houses, the 'rolling-mill,' the 'casting-house,' the 'engine-house,' and other buildings pertaining more or less to the manufacture; on the left are the 'file-forges,' where pieces of steel are brought into the rough form for files; while on the north or entrance side of the quadrangle are ranges of shops in which these pieces go through the numerous stages of progress incidental to the production of a file. Southward of the group of buildings is a wharf on the banks of the canal, where barges bring the iron from Hull and other places, and whence the finished goods are dispatched by similar conveyance. On the opposite banks of the canal are little patches of garden-ground, held by the proprietors of the Works, and let out to their workmen on the allotment system;—a plan now acted on in many manufacturing towns, and always with good results; for it gives to the workmen a healthy occupation during a few leisure hours, and at the same time cements the connection between them and their employers.

The arrangements of the various buildings depend on the nature of the processes carried on, and these therefore we will proceed to notice in the order in which they naturally occur. The making and perfecting of steel form the main or general object, while the fabrication of this steel into files constitutes one application of the material, afterwards to be noticed.

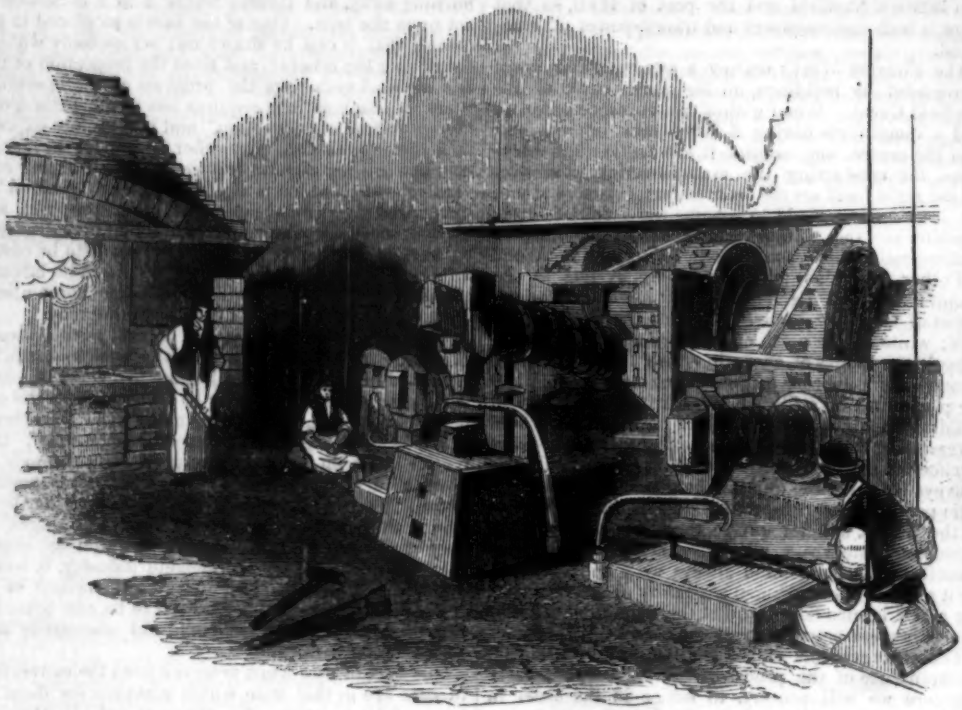
The 'converting-furnaces' are the scene of the first stage in steel-making. The object in view is to saturate iron bars with carbon to such an extent as to change their quality from iron to steel. The bars so saturated are of various widths, and are partly Swedish and partly English, according to the purposes to which the steel is to be applied. These bars, when adjusted to convenient lengths, are packed or piled up in the converting-furnaces in a singular manner. Each converting-furnace, viewed outwardly, has somewhat the shape of a glass-house, being a sort of conical covering to an oven of very large size. The oven contains two oblong receptacles or troughs, each measuring nearly twenty feet in length, about a yard deep and the same in width. They are so placed with respect to each other, that a strong body of flame may play around both of them, and raise to a high heat whatever may be placed in them.

On the bottom of each trough is placed a layer of coarsely powdered charcoal; then a layer of iron bars, placed side by side, as many as the width will admit; then another layer of charcoal; then a layer of iron bars; and so on till the trough is filled, at which time it contains more than thirty alternations of iron and charcoal. The surface is covered with a clayey substance called *wheelswarf*, derived from the abrasion or wear of the numerous grindstones used at Sheffield, made into a kind of cement or putty. A fire is kindled with Sheffield coal (which is found to be excellently adapted for this purpose), and kept up fiercely for many days. During this time the iron is in a red-hot or perhaps a white-hot state; the charcoal is also highly heated; and the iron seems gradually to absorb a portion of charcoal into the very heart of the bar. The coating of wheelswarf prevents the charcoal from burning away, and thereby leaves it in a condition to act upon the iron. One of the bars is so placed in the trough that it can be drawn out occasionally without disturbing the others; and from the inspection of this bar the workman tests the progress of the operation. Steel for coach-springs requires less of this action, or a 'lower degree of conversion,' and is therefore exposed to a lower heat than any other; steel for numerous common articles of manufacture requires a higher conversion; steel which is afterwards to be 'sheared' or hammered for knife-blades and other purposes, still higher; steel for files requires a yet higher degree of conversion; and steel which is afterwards to be cast in a fluid state requires the highest of all. The business of the steel-converter, therefore, is one of some nicety, demanding the exercise of care and judgment.

We have said that it is one of the peculiarities of Sheffield to subdivide the several stages in manufacture, and to appropriate each stage to one set of manufacturers. This system may be illustrated by the case now under notice. There are many manufacturers in Sheffield who keep converting-furnaces only; they receive the iron in bars, pass these bars through the process of conversion, and then their department is ended. The Works which we are describing, being among the few that exhibit the successive stages, are very convenient for our object; but to get an idea of the general character of Sheffield industry, it will be necessary to bear in mind that the operations of the converting-furnace are considered to be one branch of manufacture, distinct from and not necessarily associated with others.

The bars of iron when removed from the converting-furnace are in that state which procures for them the name of *blister-steel*. They have absorbed only about one per cent. of carbon, yet their quality is greatly changed. The steel, in this form, is not regarded as a material for manufactures, except for coarse goods; it is carried to a further stage before it has the necessary compactness and completeness for use in finer work, since the blisters, even if no other defects existed, would unfit it for all but coarse purposes. It obtains the name of *common steel* when, after being again heated, it is hammered with a very ponderous hammer, whereby a tougher quality is imparted to it. The most customary process to which it is next subjected is *shearing*—a name worthy to be classed among those which illustrate the odd nomenclature of manufactures. When we see 'shear-steel' stamped on table-knives, we may not inaptly imagine that it is steel which has been cut with a pair of shears; but the connection is more remote. This steel, soon after its introduction, being found suitable for making shears, it obtained the name of *shear-steel;* and by another step in the same road, the process came at length to be called *shearing*—a name about as consistent as it would be to apply the term *shoeing* to the process of tanning a calf-skin, on the ground that it makes leather fit for shoes.

The process of shearing steel is somewhat analogous to the welding of iron. It consists in heating several pieces, and hammering them one upon another, until all form one mass, greatly more dense, compact, and tough than the blister-steel from which it was made. This department of the manufacture introduces us to a part of the Works where some new features of arrangement demand our notice. The *tilt-house* or the *shear-house* is a building constructed with especial reference to strength and resistance of vibration. On entering this building we see on the left hand furnaces for bringing the pieces of blister-steel to a proper heat for welding or shearing; while before us are three hammers of enormous size and remarkable construction. The centre one of these hammers is the shear-hammer, employed in the operation now under notice; while



[Shear and Tilt-Hammers.]

the other two are tilt-hammers, for a process which will be noticed further on. Each hammer consists of a mass of iron with a steel face, fixed at the end of a ponderous mass of wood bound with iron hoops; and all these three handles are connected with a revolving shaft or drum worked by a steam-engine. There is mechanism attached to this end, whereby the huge hammer is worked up and down with great rapidity, much in the same way as hammers are used by hand. So far the arrangements seem clear enough; but it is not until we consider the vibratory and shaking action of a hammer weighing twenty cwt. in rapid motion, that we can rightly understand the necessity for enormous strength in the building. Any ordinary structure would be shaken to pieces under this visitation; and hence a foundation has to be laid to a surprising depth, to prevent this result. In the first place the drum or revolving shaft for the three hammers weighs thirty-six tons, and the bearings for this rest upon a mass of stone-work twenty feet deep, formed of ten cubical stones weighing seven tons each. Then, as the anvil or flat mass of steel on which the blows of each hammer fall, must bear up against this immense concussion, it is placed on a mass of stone weighing seven tons, and this again is supported by a tree or a trunk of timber thrust upright many yards deep in the ground, and bound round with iron hoops. Altogether, therefore, there is a vast deal of underground work to fit this tilt-house for the purposes to which it is applied.

In this building, then, the steel is sheared and tilted. The bars of blister-steel are broken up into pieces about a foot long. These are heated in a furnace or forge, and when at a white heat they are brought under the operation of the large tilt-hammer, by which they are beaten out to thirty inches in length. To change these pieces into shear-steel, half a dozen of them are put one upon another in a pile, and fixed firmly at one end in a groove or long handle. The group thus connected is placed in a furnace to 'soak,' according to a technical phrase, that is, to be partially heated, preparatory to a more intense heating. The group is taken out of this first furnace, and transferred to another, where a fierce fire brings it to a white heat. The workman attends carefully to the state of the steel while in the furnace, as great nicety is required in the degree and equalization of the heat attained. When sufficiently heated, the group (still held by the handle) is taken out of the fire and placed under the largest or shear-hammer, where it is beaten on all four sides until all the pieces become thoroughly amalgamated or welded one to another, and the result appears in the form of a bar of steel two or three inches square. Each hammer has a kind of blast-pipe, to blow dust and dirt from the anvil beneath. In some cases the bar is cut in two, heated again, and again welded, whereby the process is carried still further. According to the degree to which it is welded or sheared, the steel is called 'double-shear,' 'single-shear,' or 'half-shear.' During the heating in the furnace, preparatory to the hammering, the group of pieces requires a degree of attention whereby the workman is exposed to a very intense heat.

The shear-steel made by this process, when closely examined, is found to have lost all the flaws and blisters which distinguished it as blister-steel, to have acquired a uniformity of character throughout, and to be greatly more malleable and tenacious than it was before.

There is, however, yet to be described a kind of steel more important than either of those hitherto described, and one to which the beauty of modern steel goods is in great part indebted: we allude to *cast-steel*. As the heat employed in melting steel is the greatest which the manufacturing arts of any country exhibit, the furnaces, the crucibles, and all the apparatus employed must be so formed as to endure this heat; and we must therefore notice these appliances before we can understand the process itself.

The crucibles or melting-pots are rather less than

two feet in height, and have a somewhat sugar-loaf shape. They are made of Stourbridge clay, wrought to the greatest possible degree of uniformity and smoothness. To give this uniformity, the clay, after being mixed with water and well worked up, is spread out in a thin layer on the floor of a room under the casting-house. Two men, with naked feet, tread or trample on the clay uninterruptedly for five or six hours,—walking, or jumping, or dancing, or shuffling

(for it is hard to know which to call it) over and over again from side to side, and from end to end, until every particle of clay has been trodden repeatedly. It might seem strange why some kind of mill should not be employed in this operation; but those who are most likely to understand the matter state that no other method equals this for bringing the clay to a perfect uniformity of substance, and expelling all air-bubbles. When the clay is prepared, it is made into crucibles weighing about twenty-six pounds each, by fashioning it in a mould having a core to give the internal form. The crucibles, as they are made, are placed in a vault where both air and warmth can come to them; and when dried by this means, they are placed, on the night before they are to be used, on an annealing grate, where they are covered with cinders, and allowed to remain till the next day. These operations of crucible-making are continued uninterruptedly; for notwithstanding the care and trouble bestowed, each crucible will only last one day. At these Works about a hundred and fifty are made and worn out every week.

The cast-house consists of two rooms or compartments, both paved with stone, and each containing six melting-furnaces. These furnaces are very different from others which we have had to mention; for they exhibit to the eye nothing but a hole in the floor about eighteen inches square. There are six of these holes in a row in each shop; and so long as they are covered by iron covers or lids, there is nothing particular to be seen; but when one of these lids is removed a fearfully intense heat is shot upwards from beneath. Each hole is the mouth of a furnace; and each furnace is a cell measuring about four feet deep by eighteen inches square, being merely large enough to contain two crucibles with the requisite quantity of fuel. There is a grate beneath, through which a powerful draught ascends to the fuel; and there is a flue at one end to carry off the smoke and heated gases. Neither bellows nor blast-engine is used; the intense heat being wholly excited and maintained by the judicious admission of air from a vaulted chamber beneath. The walls of these small furnaces are exposed to such a destructive temperature, that the selection of the material with which they are lined becomes a matter of much importance. This material obtains the name of *ganister*. It is a kind of stone found near Sheffield, and is used in the first instance as road-metal; after which, when ground to dust by wheels and horses' feet, it is collected and made into a plaster or lining for the furnaces.

Let us now see what passes in one of these cast-houses. Each crucible-full of metal requires about four hours to effect its perfect fusion; and there are three successive meltings in twelve hours. Each furnace is supplied with coke to a certain height; and the two pots or crucibles are adjusted within it, side by side. More coke is then thrown in, until both pots are entirely surrounded by it. Here they are left to be acted upon by the fire, until they are brought to a dazzling white heat. The cover of the furnace is opened, and a long funnel made of sheet-iron is let down into each pot, having its open end at a convenient height above. The steel, broken up into small fragments, and amounting to thirty or forty pounds for each pot, is thrown into the funnel, and allowed to fall down into the pot. The funnel is then removed, the cover put upon the pot, coke added so as to enclose it completely, and the lid of the furnace put on. From time to time, during the ensuing period of four hours, the lid is removed, and the progress of the melting watched, more and more coke being added when necessary; so that ultimately there are from four to five tons of coke used in melting one ton of steel.

As the time approaches for the casting, the men make preparations which sufficiently indicate the sort of "Fire-King" ordeal to which they are about to be exposed. They cover their legs and body with coarse sacking or leather, saturated with water from a trough at hand, and prepare to fill the ingot-moulds with the melted steel. These moulds are formed of metal, so shaped as to give oblong bars or ingots weighing from thirty-six pounds to two hundred pounds each, according to circumstances. Each mould is divided into two halves, which halves are bound closely together when the casting is about to take place. The mould is first coated on the inside with a kind of oily composition, closed up tightly, and placed vertically in a hole in the stone floor of the cast-house, with the upper end open. One of the men draws off the lid of a furnace, and the white-hot coke is removed from about the pot which is about to be emptied. A man then takes a long instrument acting like pincers or tongs, hovers over the furnace in a manner which is almost fearful for a spectator to witness, puts the tongs down into the furnace, grasps one of the pots firmly, and draws it up; having during this time his face directly over a furnace so intensely heated as to convert steel into a liquid, and drawing up, in this hazardous position, a white-hot crucible weighing with its contents sixty pounds. He rests the glowing mass with its lower end on the floor; another man strikes off some of the adhering slag with a long iron bar; a third man grasps the crucible with an instrument held horizontally; the first man loosens his hold, and with his tongs takes off the cover of the the crucible; the third man lifts up the mass (no trifling weight when held horizontally at the end of a bar), goes to the ingot-mould, and pours the liquid

steel into it; while a fourth man, standing before him, clears the liquid stream from any impurities as it flows, by means of a long rod. Thus all four have their prescribed office; and no description can give an adequate idea of the scene which is presented. The terrible yawning mouth over which the first man hovers, the glowing mass which he draws forth, the intense whiteness of the liquid steel as it flows into the mould, the profusion of delicate greenish sparks which shoot forth during the pouring—all form a spectacle which, when once seen, will not be soon forgotten.

The part of this operation which exposes the workman to the greatest heat is that of drawing the pot from the furnace; but the part requiring most skill is that of 'teeming,' or pouring into the mould, since it is necessary that the liquid stream should fall directly down the centre of the mould, without striking against the sides more than can be avoided. The eyes of the men are weakened by the intense glare to which they are exposed, but it does not appear that the general health suffers in any marked degree; yet a stranger may well marvel how any human frame could bear such a trial for years together.*

Immediately after each pot is emptied, it is returned again to the furnace, again brought to a white heat, again filled with pieces of steel, and again exposed to four hours' heating. After this has occurred three times, or one entire day, the melting-pot has rendered its services, and is then cast aside to be replaced by another. With regard to the steel thus melted, certain important changes have taken place within the last few years. It has often been conjectured that the Swedish iron derives some of its valuable properties from the presence of a small quantity of manganese; and within the last few years manganese has been introduced as a material to be added to the bar-steel in the melting-pot, in order to impart to the cast-steel certain valuable qualities which it did not possess before this improvement was introduced—such as a facility for being worked up into certain articles of cutlery. The history of the invention is rather complicated, and involves some of those unpleasant features of which our patent-laws exhibit too many examples. The invention was, we believe, placed in a practical form and patented by a Mr. Heath; but through certain technical flaws in the specification, the method has become thrown open to all: Sheffield has been greatly benefited, but the inventor has not. There is now a large quantity of carburet of manganese used weekly by the steel-melters of Sheffield; and the use of cast-steel for table-knives and other articles of cutlery has been one of the results of the invention. The matter is not one for discussion here; but it seems a pity that an invention which benefits a whole town should not benefit the inventor.

If the cast-steel is for the purpose of making saws, the ingots are rather flat, so as to be conveniently rolled into sheets at the rolling-mill; but if for other purposes, they are generally about as thick as they are wide. The rolling of steel into sheets or into bars is so precisely analogous to that observable in the iron-manufacture, that the same description suffices for both. The rolls are very ponderous, weighing as much as five hundred pounds each; and when they are about to be used, the steel, whether 'shear' or 'cast,' is heated in an adjoining furnace, and passed repeatedly between the rolls while yet red-hot, by which it assumes the form either of bars of any required shape or of sheets.

* To illustrate the dangers of the occupation, we may state that the man represented in the act of 'teeming,' in our frontispiece, has, since the sketch was taken, nearly lost his eye-sight, from a sudden shower of sparks occasioned by a too great dampness of the mould into which he was pouring the liquid steel.

The *tilting* of steel is another curious process, the object of which is to close the pores of the steel, and to render it as dense and compact as possible. All steel for the best articles is tilted before being applied to use, whether it be 'shear' or 'cast.' The tilting is one of the operations carried on in the building described in a former paragraph as being constructed with such great strength. There are two swings or suspended cradles in the tilt-house, one near each tilt-hammer. In these swings the men sit while holding the bars of steel to be tilted; since they can move their bodies to and fro (to bring every part of each bar under the operation of the hammer) more easily when they thus sit, paddling along with their feet, than if they stood or walked. The bars of steel are heated to a certain temperature in an adjoining furnace, and are then brought under the action of the tilt-hammer, where a deafening clatter is kept up for some minutes, accompanied by a vibration all around, which would shake to pieces any but a building of great strength.

It is one of the peculiarities of Sheffield that tilting is a trade by itself. In a map of the town we may see marked Mr. So-and-so's "*Tilt*;" for with the usual brevity of technical language, the whole building, with its hammers and furnaces, is called a tilt. These tilts are mostly situated on the banks of some one or other of the rivers which flow through Sheffield; and it is impossible to mistake them when once in their neighbourhood. There is one, for instance, close to the Lady Bridge, where from morning till night there is an incessant thumping, which shakes the very roadway itself. These tilters, or proprietors of tilt-works, receive steel in the form of bars, from any parties, and pass it under the tilt-hammers; after which their occupation is ended. At a few of the Works, such as those which form the subject of this paper, the tilting is combined with the other branches; but it may, nevertheless, be deemed a distinct branch.

We must now transfer our attention to that portion of the works which is appropriated to the *File-manufacture*.

These tools, simple and unimportant as they may seem, and probably do seem, to those who never enter an artisan's workshop, are among the most note-worthy articles made of steel. They are the working-tools by which every other kind of working-tool is in some degree fashioned. Whether a man is making a watch or a steam-engine, a knife or a plough, a pin or a coach, he would be brought to a stand if he had not files at his command. It may be a file with a hundred serrations to an inch, or with six or eight; it may have straight cuts like most files, or angular holes like a rasp; it may be two inches long, or a yard long; it may be round, or half-round, or triangular, or square, or flat; blunt or pointed, straight or curved;—but a file of some sort or other will be found in almost every workshop.

The first place to which we have to follow the file-makers is the *forge*. On the eastern side of the quadrangle of the Works is a range of sixteen arches or compartments, all opening one into the other. Each compartment is fitted up with all the appliances for forging files. There is on one side a forge-fire, with a hearth on which to place the fuel, and bellows placed behind, much in the same way as a common smith's forge, but with more attention to neatness and order. The workman's bench, if we may use such a term, is a large block of hard stone, weighing about three tons, and placed firmly on the earthen floor of the smithy or forge. On this are fixed one or more steel anvils, adapted by their size and shape to support the pieces of bar-steel while being forged into the form of files. There are also hammers of various sizes and peculiar shapes, and other small implements necessary to the

operation. The forges are arranged along an arched avenue so that all are airy and free from any great intensity of heat, except at the precise spots where heat is required. A file ought to be made of the very best steel, and is so, unless—like the razors mentioned by Peter Pindar, or the gross of green spectacles immortalized in the 'Vicar of Wakefield'—they are merely "made to sell." If a file be too soft, the whole toothed surface would be crushed down when applied to use; if too hard, the teeth would fly or break off at every stroke; so that very great care and skill are required in the manufacture; and a firm which has once acquired a reputation for good files is extremely solicitous not to damage it by the sale of even one that is defective.

The bars of steel are selected according to the size and shape of the files to be made, and when cut into pieces, each piece is placed among the burning fuel on one of the forges, and quickly brought to the required temperature. Except for the smallest files, there are two men employed at each forge—a *striker* and a *forger*, one of whom manages the fire, heats the steel, and acts as a general assistant; while the other is the superior

workman, who hammers the file into shape, and is responsible for its quality. There are various notches, ridges, curvatures, and gauges, on and about his small steel anvils, which enable him to work the piece of steel into the proper form for a file, including the narrow handle or 'tang.' The rate of working is such, that at the whole of the sixteen 'hearths' about fifty thousand dozens of files are made in a year. Each man accustoms himself to the making of one particular size of file, so that in passing along the range of forges, from one end to the other, we begin at the smallest files, and go on gradually to the largest. From the thickness and softness of the heated metal, there is very little rebound to the hammer, and this renders the work of the striker rather laborious, especially for large files, where a hammer of nearly twenty pounds weight is used.

The files are then annealed or 'lighted,' in order to bring the steel to a state of softness fitted for the cutting of the teeth. This is done by placing them on a kind of brick hearth in a furnace, and exposing them for several hours to a temperature determined by experience; then, without removing them, they and the oven are allowed to cool very slowly, by which the steel becomes annealed to a softness suitable to the subsequent operations.

Next succeeds the process of *grinding*, whereby the files (or 'blanks,' as they are yet termed) are ground down to a true and regular surface, whether that be flat or curved. In one part of the Works is a building where several grindstones of various sizes are ranged in a row, all turned by the steam-engine which works the tilt-hammers. Each grindstone is occupied by one man, who sits astride over a 'horse' or beam behind it, and leans over the grindstone, applying the file to the surface of the revolving stone in such a manner as to grind the former to a true and correct form. The process is wet and dirty, from the mixture of fragments of stone and steel with the water used in wetting the stone; and the attitude in which the grinder works renders the process rather a laborious one.

Then ensues the very important and curious operation of cutting the files, one which has hitherto defied the powers of machinery in an extraordinary manner. In one of the buildings of the works is a long room in which file-cutters are ranged round the sides in front of the windows, as in the next sketch, each one having a small bench before him with a simple apparatus for fastening down the file while being cut. The men range themselves according to the kind of file which they are cutting, each man confining himself pretty nearly to one size of tooth, and all placing themselves in the gradation of these sizes.

The file being slightly strapped down, the cutter takes a sharp tool or chisel in the left hand and a hammer in the right. This tool is a very hard, sharp, and tough piece of steel, having an edge fitted to produce the required kind of tooth, and a head to receive the blow of the hammer. The hammers employed (the heaviest of which weigh about nine pounds each) have the handle placed in a remarkable manner with respect to the head, being adapted at such an angle, that the cutter can, while making the blow, *pull* the hammer in some degree towards him, and thus give a peculiarity to the shape of the tooth. If the file is a flat one, or has one or more flat surfaces, the cutter places the small steel tool on it at a particular angle, and with one hammer-blow cuts an indentation. He then, by a minute and almost imperceptible movement, changes the place of the tool, and makes another cut parallel to, and a short distance from, the first; then a third, a fourth, and so on to the end of the file, shifting the file slightly in its fastening as he proceeds. Generally the file is cut doubly, one set of cuts crossing the other at an angle more or less acute. In this case he reverses the position in which he holds the cutting tool, and proceeds as before. If the file be round or half-round, or have a curved surface of any kind, he still uses a straight-edged cutting-tool; but as this can only make a short indentation, he has to go round the file by degrees, making several rows or ranges of cuts contiguous one to another.

Such is the art of file-cutting; and it contains many points worthy of remark. In the first place, the angle at which the cuts are made depends greatly on the purpose to which the file is to be applied, and is made an especial object of the cutter's attention. In the next place, the cut is not a mere indentation, made without reference to form; it is a triangular groove of particular shape, the production of which requires a

most discriminating tact in the management both of the hammer and of the cutting-tool. Then again, the strict parallelism of the several cuts can only be brought about by practised accuracy of hand and eye, since there is no guide, gauge, or other contrivance for regulating the distance. In a round file, too, the several rows or cuts are brought side by side in such an exact manner, that it is difficult to conceive them to be formed singly and by hand. As an instance of what skill and long practice can effect in this respect, we have before us a file about ten inches long, flat on one side and round on the other; the flat side is cut with a hundred and twenty teeth to an inch, so that there are about twelve hundred teeth on that side; the round side has such an extent of curvature, that it required eighteen rows of cuts to compass it; each little cut on this side is not much above a twentieth of an inch in length; and the number is thus so great, that for the whole file there are twenty-two thousand cuts, each made with a separate blow of the hammer, and the cutting-tool being shifted after each blow!

It may well be asked—why is not this done by a machine? Machines in great number have been suggested, in France, in England, and in the United States: some by mere theorists, some by practical men; some have never extended beyond the drawn plans, while some have actually been set to work. Yet for some reason or other all these have failed to maintain their position: they have been tried, commented on, admired, and rejected. Not long ago a very ingenious machine, invented by a gentleman of high mechanical skill, was talked of highly in respect to its fitness for this purpose. But we believe that at the present time the whole of the files made at Sheffield (the headquarters of the trade) are cut by hand. The grounds of this want of success involve matters too technical for us to enter upon here; but we believe that one difficulty lies in this point—that if one part of the file happens to be in the slightest degree softer or narrower than the rest, any machine employed would make a deeper cut there than elsewhere; whereas a workman who has been employed in the trade from a boy (and none others, it is said, can acquire the requisite skill) can feel instantly when he arrives at any variation in the quality or condition of the steel, and at once adapts the weight of his blow to it.

When the files are cut, they are brought into the warehouse to be stamped with the corporate mark of the firm. They are next *hardened*, the steel having been before purposely rendered soft for the facility of cutting. This hardening involves details of some nicety, and the proper working of the file depends a good deal on the manner in which it is done. In one of the buildings is a long tank or trough, containing a saline liquid, and behind this are six hearths for heating the files. When each file has been heated to a certain temperature, it is plunged suddenly into the

liquid, and while yet warm is straightened by a small apparatus at hand. A mixture of alegrounds, salt, and other substances is also employed during this process.

The files are then scrubbed clean by women with sand and water; and lastly pass into the hands of the foreman, who tests every file singly in a way which brings both the hearing and the touch into exercise. He strikes the file gently on a piece of hard steel, and also rubs it gently from end to end; from the sound he judges whether the internal quality of the steel is good; and from the tremulous movement or friction he judges whether it is tempered to the degree of hardness required; nay, it is said that, even if deaf, an experienced man could tell this by the tremulous motion given to his fingers and wrist.